LOW CARBON STRUCTURAL STEELS (ACCIAI AL CARBONIO DI QUALITÀ)

Fondamentalmente acciai C-Mn con struttura ferritico-perlitica con $\sigma_y \sim 500$ N/mm^2

Possono venire temprati e rinvenuti→ $\sigma_y \sim 700$ N/mm^2

Usi:

- Ponti
- Serbatoi in pressione
- Navi
- Piattaforme offshore
- Pipeline
- Etc. (molte applicazioni in impianti chimici)

Una delle richieste più importanti per questi acciai, e per queste applicazioni, è la loro

- **saldabilità (problema navi Liberty)**
- **tenacità**
- **duttilità**

Agli inizi degli anni '50 il lavoro di Hall e Petch fece comprendere l'importanza delle dimensioni dei grani → vennero prodotti acciai con $\sigma_y \sim 300$ N/mm^2 usando Al per affinare il grano.

Più tardi si capì l'importanza dell'indurimento per precipitazione (aggiunte di Nb-V-Ti ~0.15%) → si svilupparono gli HSLA (high strength low alloy) con $\sigma_y > 500$ N/mm^2.

Per aumentare ancora di più la resistenza, negli ultimi anni si è fatto sempre più ricorso alla laminazione controllata (controlled rolling) che poi associata anche ad un ciclo termico controllato ha dato origine ai processi termomeccanici (thermomechanical processing); in questi ultimi casi però diventa fondamentale controllare la purezza e le inclusioni presenti nell'acciaio.

Si è visto poi che è importante usare acciai con elementi che formano carburi (~ 0.05% Nb) (NbC e TiC sono stabili fino a 1150÷1300°C).

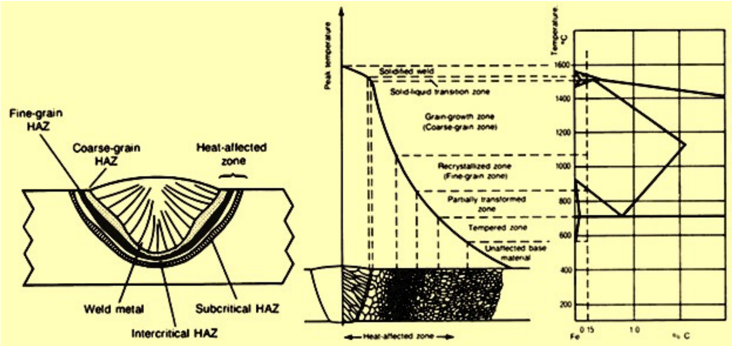
Weldability of Steels

A good understanding of the chemical and physical phenomena that occur in the weldment is necessary for welding modern steels.

Therefore, the influence of operational parameters, thermal cycles, and metallurgical factors on weld metal transformations and the susceptibility to hot and cold cracking are very important.

The carbon and low-alloy steels group comprises a large number of steels that differ in chemical composition, strength, heat treatment, corrosion resistance, and weldability. These steels can be further divided into subgroups:

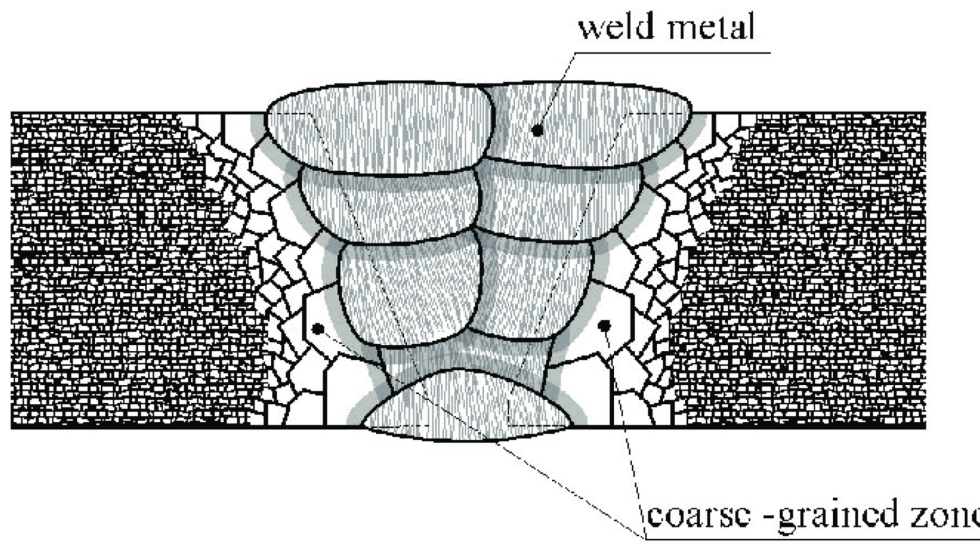
- Carbon steels
- High-strength low-alloy (HSLA) steels
- Quenched and tempered (QT) steels
- Heat-treatable low-alloy (HTLA) steels
- Precoated steels



Solidified weld structure and different HAZ regions of a single pass weld in steel with 0.15 % C

Under conditions of rapid cooling and solidification in the weld metal, alloying and impurity elements segregate extensively to the center of the interdendritic or intercellular regions and to the center parts of the weld, resulting in significant local chemical inhomogeneities.

The chemical composition remains largely unchanged in the **HAZ** because the peak temperature remains below the melting point. Nevertheless, considerable microstructural change takes place within the HAZ during welding as a result of the extremely harsh thermal cycles.



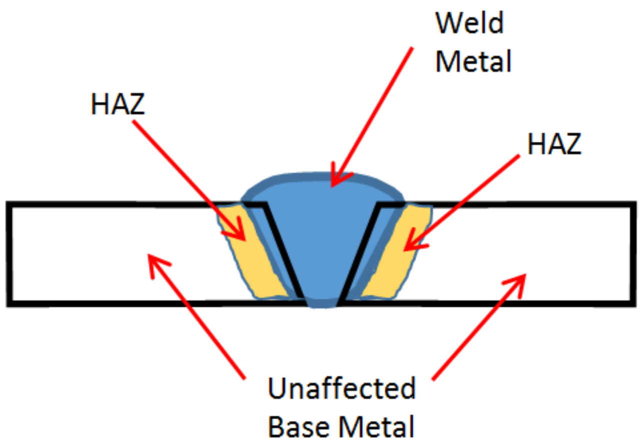
The material immediately adjacent to the fusion zone is heated high into the austenitic temperature range. The precipitates get generally dissolved and unpinning of austenite grain boundaries occurs with substantial growth of the grains, forming the coarse grain in the HAZ region. The average size of the austenite grains, which is a function of the highest temperature attained, decrease with increasing distance from the fusion zone. The cooling rate also varies from point to point in the HAZ region.

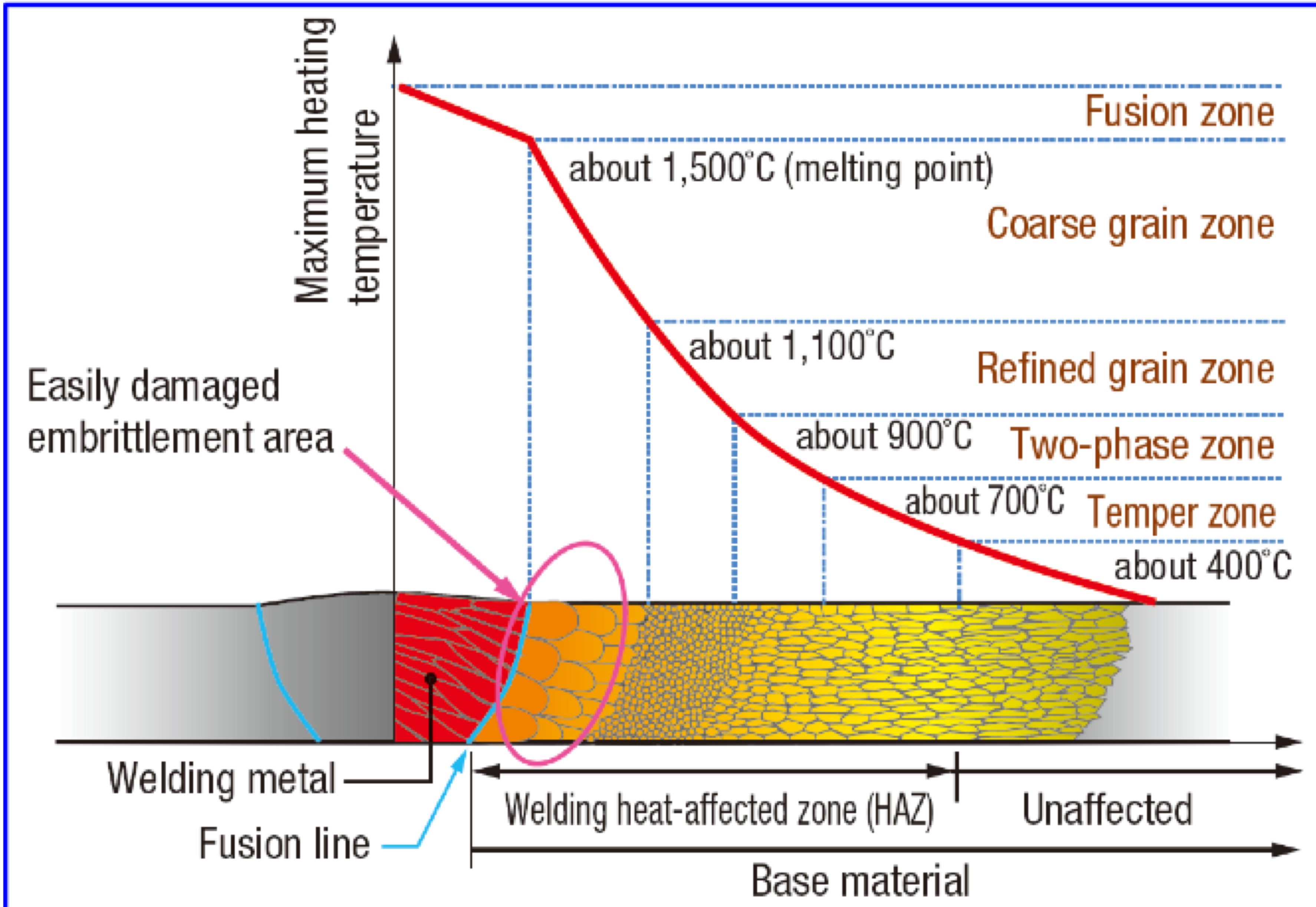
Metallurgical Factors That Affect Weldability

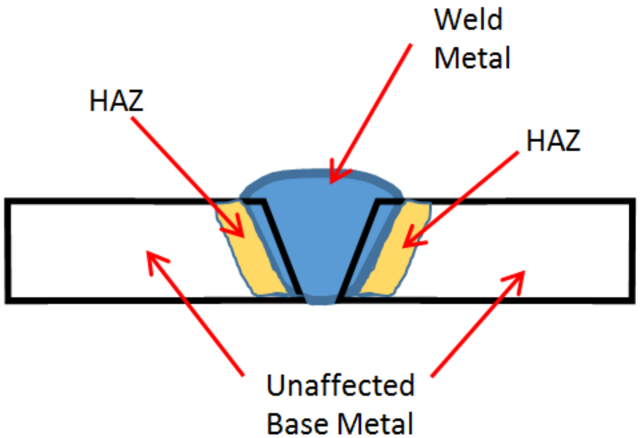
Traditionally, empirical equations have been developed experimentally to express weldability. **Carbon equivalent (CE)** is one such expression; it was developed to estimate the cracking susceptibility of a steel during welding and to determine whether the steel needs pre- and postweld heat treatment to avoid cracking.

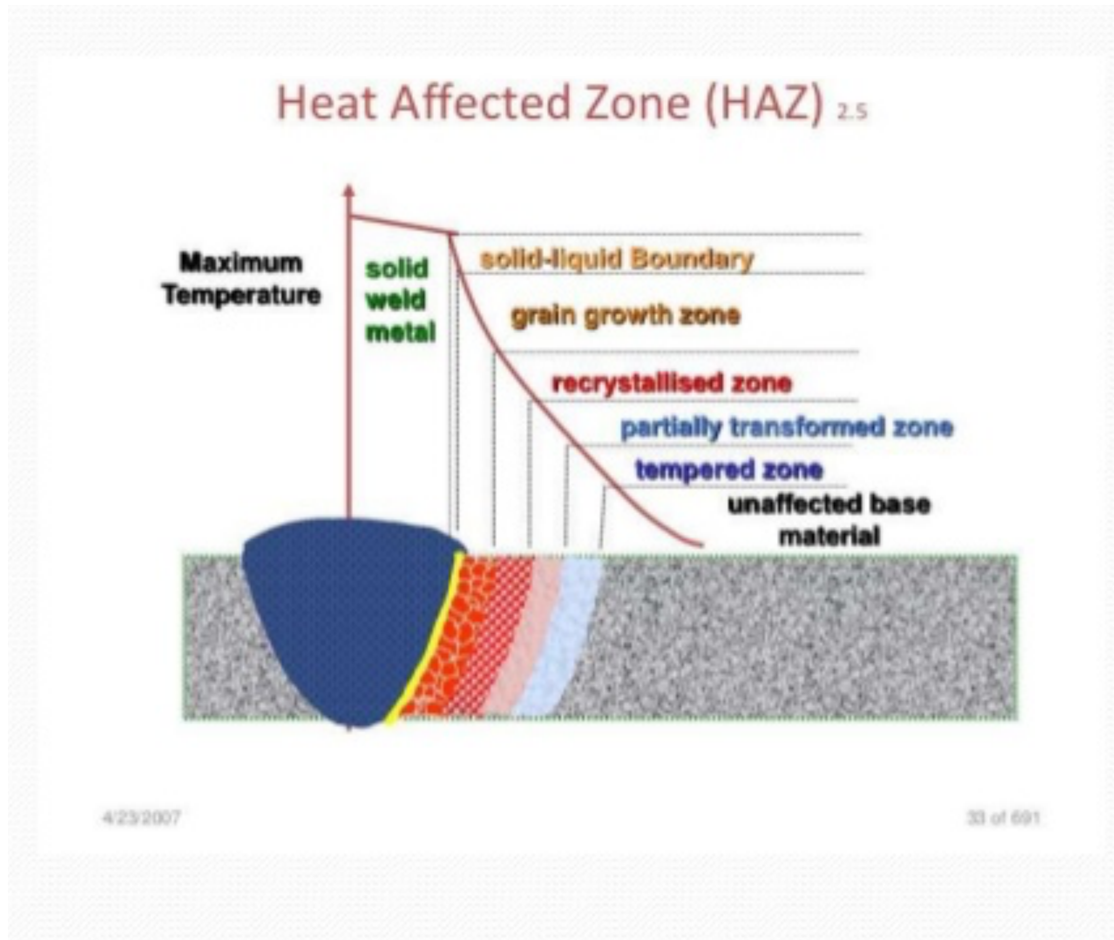
The International Institute of Welding (IIW) carbon equivalent equation is:

$$C_{eq} = C + (Mn/6) + (Ni/15) + (Cu/15) + (Cr/5) + (Mo/5) + (V/5)$$




Maximum heating temperature
Fusion zone
about 1,500°C (melting point)
Coarse grain zone
about 1,100°C
Refined grain zone
about 900°C
Two-phase zone
about 700°C
Temper zone
about 400°C
Easily damaged embrittlement area
Welding metal
Fusion line
Welding heat-affected zone (HAZ)
Unaffected
Base material





When the CE of a steel is less than 0.45 wt%, weld cracking is unlikely, and no heat treatment is required. When the CE is between 0.45 and 0.60 wt%, weld cracking is likely, and preheat in the range of approximately 95 to 400 °C, is generally recommended. When the CE of a steel is greater than 0.60 wt%, there is a high probability that the weld will crack and that both preheat and postweld heat treatments will be required to obtain a sound weld.

Weld Cracking

- Hydrogen-Induced Cracking

  Moisture pickup from the atmosphere that is incorporated into the molten puddle, either directly or via the welding consumables, is the main source of hydrogen

- Stress-relief cracking

- Hot cracking

  The partition and rejection of alloying elements at columnar grain boundaries and ahead of the advancing solid/liquid interface produce significant segregation. The elements of segregation form low-melting phases or eutectic structures. They weaken the structure to the extent that cracks form at the boundaries under the influence of the tensile residual stresses during cooling.

Toughness

TOUGHNESS is an indication of the capacity of a steel to absorb energy and is dependent on strength as well as ductility.

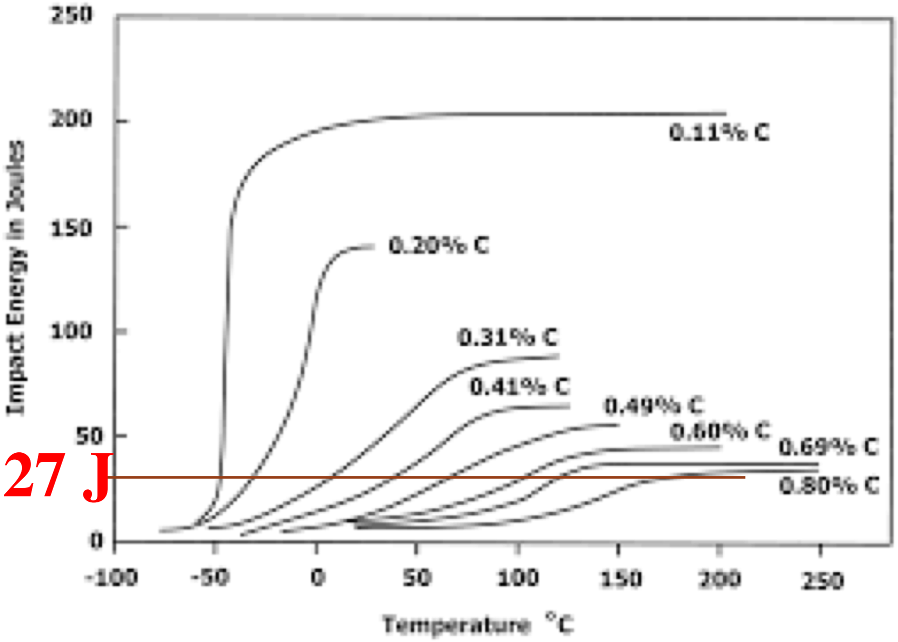
All carbon and high-strength low-alloy (HSLA) steels undergo a ductile-to-brittle transition as the temperature is lowered.

Depending on chemical composition, product processing, and service environment, this transition can occur at temperatures from several hundred degrees above to several hundred degrees below room temperature.

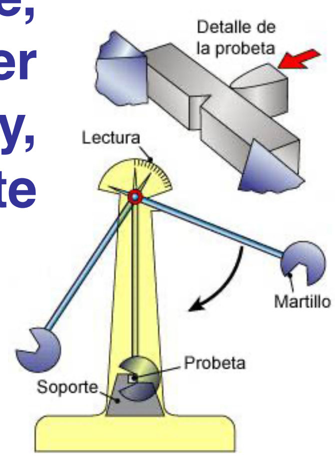
World War II provided the impetus to build 2,710 ships known as Liberty ships.

About 30% of all Liberty suffered from cracks during the war, and 3 were lost when the ship suddenly split in two.

The cause of the failures was discovered by Constance Tipper, an engineering professor at Cambridge. She found that the steel used suffered from embrittlement, in which materials become brittle. Ships operating in the North Atlantic were often exposed to temperatures below a critical temperature, which changed the failure mechanism from ductile to brittle. Because the hulls were welded together, the cracks could propagate across very large distances; this would not have been possible in riveted ships.



Pearlite and ferrite have the highest transition temperature, followed by upper bainite and, finally, tempered martensite or lower bainite.



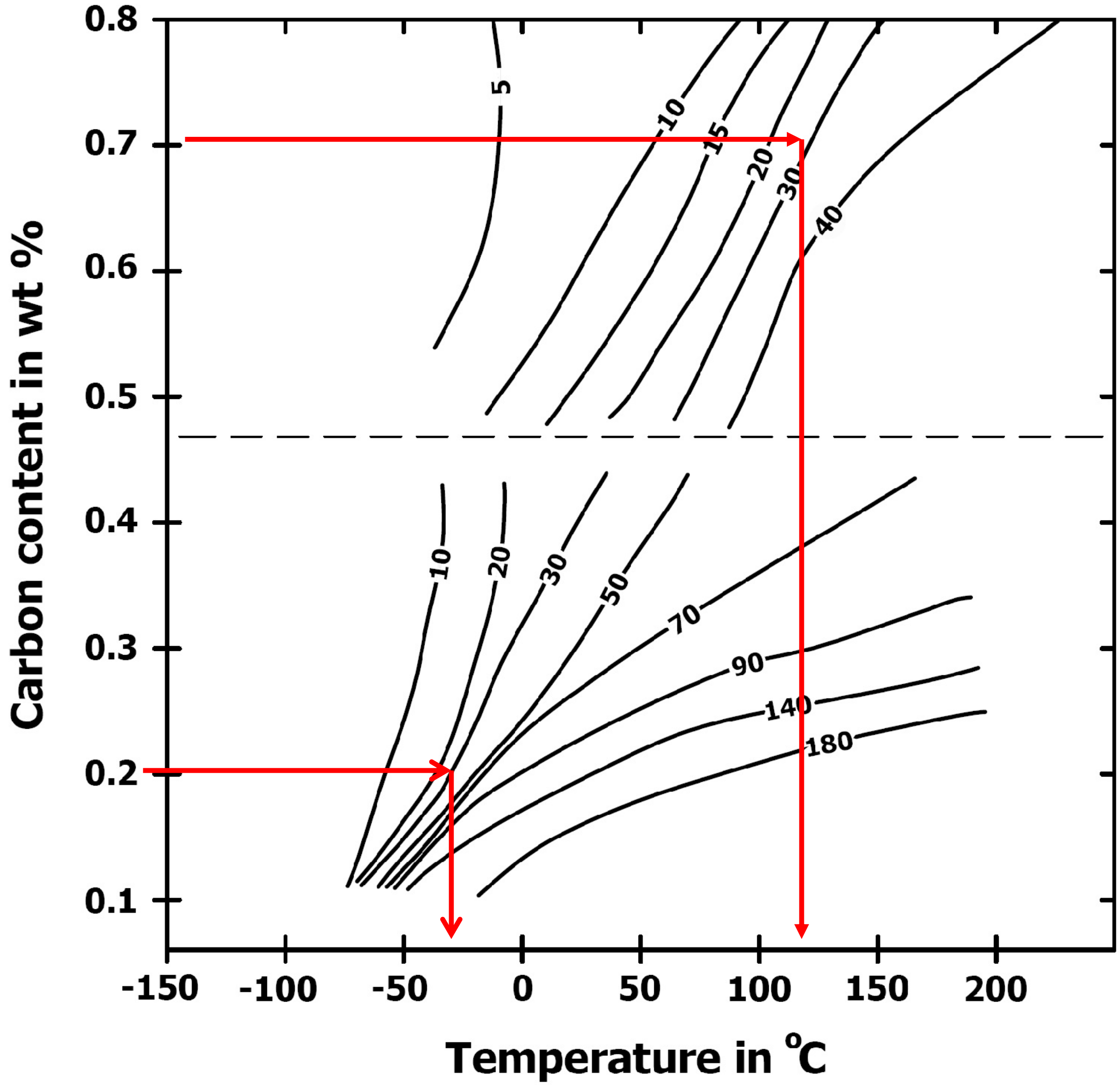
C Increasing carbon content increases transition temperature and decreases fracture energy primarily as a result of increased strength and hardness.

Mn In low-carbon steels, it can substantially reduce the transition temperature. *In higher-carbon steels, manganese may be less beneficial*.

Ni like Mn, is useful for improving the toughness

S in amounts up to about 0.04% has a negligible effect on notch toughness

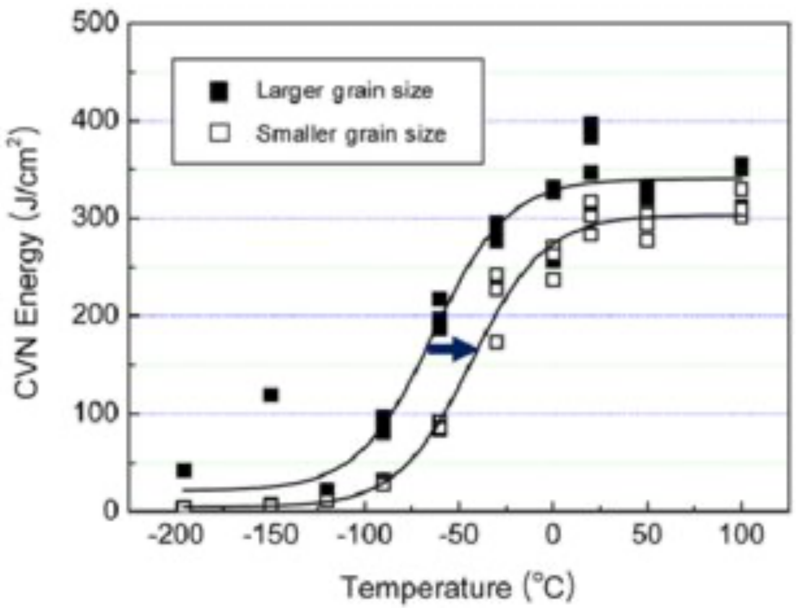
P has a strongly deleterious effect on the toughness. It raises about 7 °C for each 0.01% P



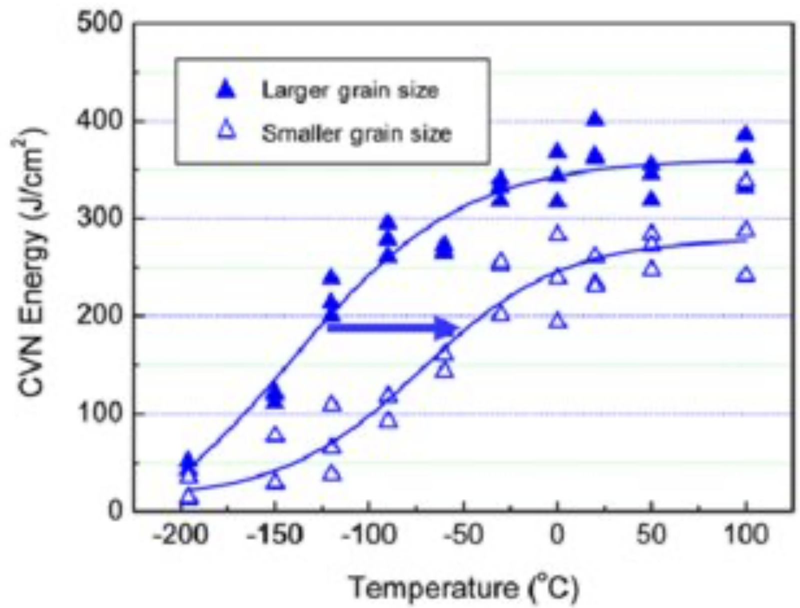
The dependence of the Charpy V-notch impact energy of irons and plain carbon steels on carbon content and temperature.

Grain Size

a decrease in grain size reduces the transition temperature. In addition to improving toughness, a fine grain size increases the strength of steel. **Thus, refinement of grain size is the most important and most effective way to increase both strength and toughness**.



(a)



(b)

ACCIAI MICROLEGATI
High Strength Low Alloys

Gli acciai microlegati sono acciai che pur con un basso tenore di elementi aggiunti in lega mostrano elevate caratteristiche di resistenza.

Sono spesso indicati con la sigla HSLA (acronimo di high-strength low-alloy).

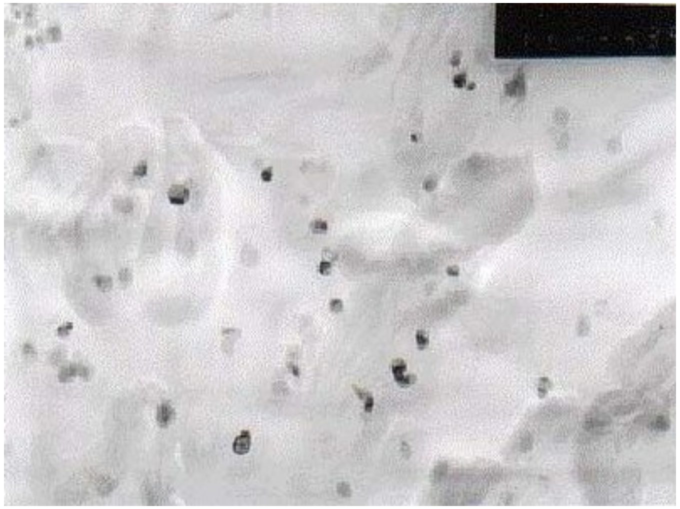
La classe di acciai microlegati non è definita in modo preciso all'interno della normativa tecnica e vengono compresi nella classe degli acciai al carbonio da costruzione e di uso generale, in quanto gli elementi aggiunti in lega sono presenti in piccole quantità.

I microalligati possono comunque essere riconosciuti dagli utilizzatori, in quanto nella composizione chimica viene esplicitamente dichiarata la presenza di almeno uno degli elementi generalmente usati per la microalligazione: **titanio (Ti), vanadio (V), niobio (Nb) e boro (B).**

Le caratteristiche meccaniche, degli acciai microlegati o HSLA, sono dovute sia alla composizione chimica che ad un particolare trattamento termomeccanico, che viene di solito eseguito semplicemente mediante uno stretto controllo della temperatura e del percorso di raffreddamento al termine delle operazioni di deformazione plastica a caldo senza l'onere di eseguire successivi e specifici trattamenti termici.

Come detto, gli HSLA sono acciai al C-Mn contenenti piccole quantità, di solito al di sotto dello **0.15%** in peso, di **V, Ti, Nb** che mostrano una spiccata tendenza a combinarsi con **carbonio (C) e all'azoto (N)** a generare composti di dimensioni nanometriche. La formazione di carburi, nitruri e carbonitruri, produce un affinamento dei grani dell'acciaio. Il contenuto di carbonio generalmente presente varia da valori prossimi a 0.03-0.04% fino al contenuto eutettoidico (0.77%)

σ_y varia tra 350MPa a 550 MPa, anche se sono stati recentemente sviluppati gradi con lo 0.2% C che arrivano a 1100 MPa, ma a volte presentano significative limitazioni circa la tenacità se non si realizzano adeguati cicli termici



NIOBIO:

dà origine a carburi e a carbo-nitruri che affinano il grano. The optimum Niobium concentration in the low-carbon steels is 0.04% and this concentration makes it possible to increase the yield point of products by about 120 MPa due to refinement of grains and by about 160 MPa due to precipitation hardening by the dispersive NbC particles, **with the simultaneous lowering of the T_{D-F} temperature by about 40°C**

BORO: si deve usare cautela perche' si può arrivare ad una maggiore fragilità se si combinasse in grande quantità con l'N_2 anziché con il C

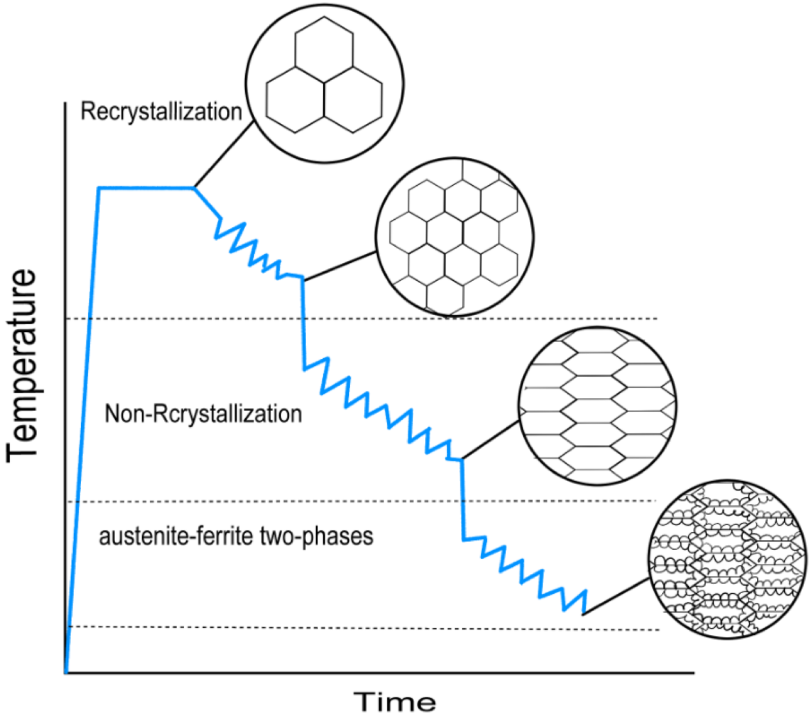
VANADIO:

la sua azione è sentita ed apprezzabile anche solo con un tenore dello 0.05%. Forma carburi che producono l'effetto di indurire sensibilmente l'acciaio. Il V affina molto il grano.

TITANIO:

è un energico disossidante con conseguente miglioramento delle caratteristiche meccaniche.

Conferisce un indurimento per precipitazione e quindi anche un innalzamento del carico di snervamento; questo effetto del titanio è dovuto alla eccezionale stabilità dei carburi cui dà luogo. Il titanio è anch'esso un energico affinante del grano.



Strengthening Mechanism

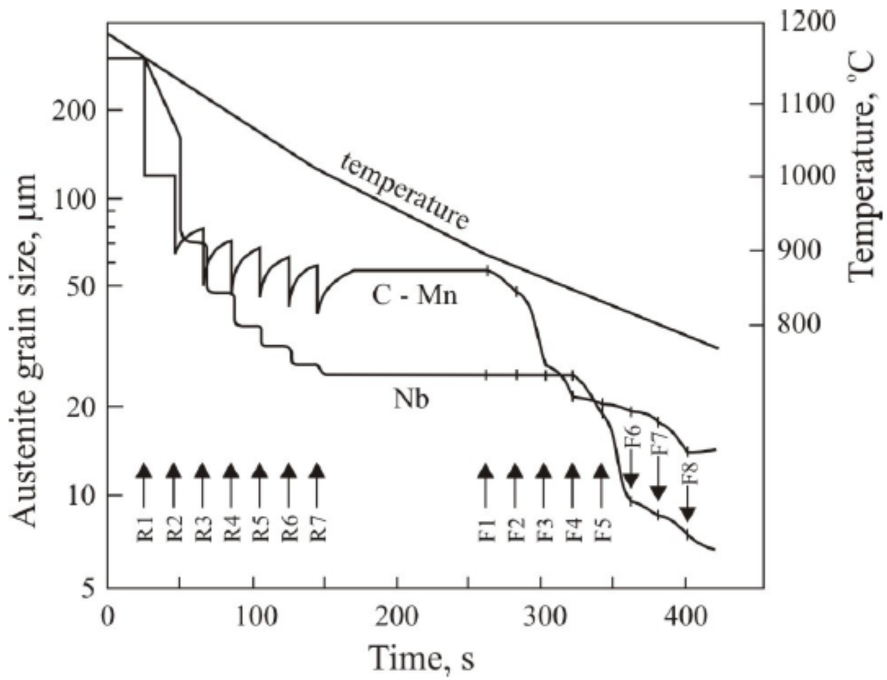
Control-rolled HSLA steels contain a combination of different strengthening mechanisms. The main strengthening effect come from grain refinement. The other mechanisms include solid solution strengthening and precipitate hardening from micro-alloyed elements. After the steel passes the temperature of austenite-ferrite region, it is then further strengthened by work hardening

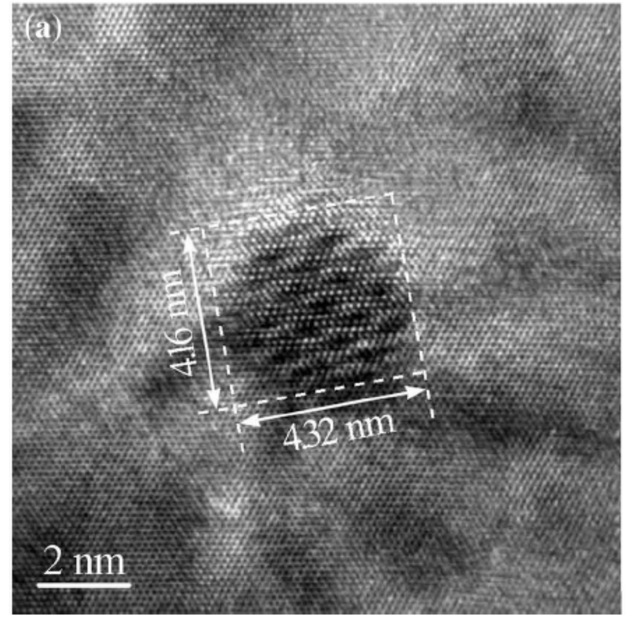
Controlled rolling is a method of refining grains by **introducing large amount of nucleation sites for ferrite in austenite matrix** by rolling with temperature control. There are three main stages during controlled rolling:

1) Deformation in recrystallization region. In this stage, austenite is being recrystallized and refined and can thereby refine the ferrite grains in the later stage.

2) Deformation in non-recrystallization region. Austenite grains being elongated by rolling and deformation bands might present. Elongated grain boundaries and deformation bands are all nucleation sites for ferrite.

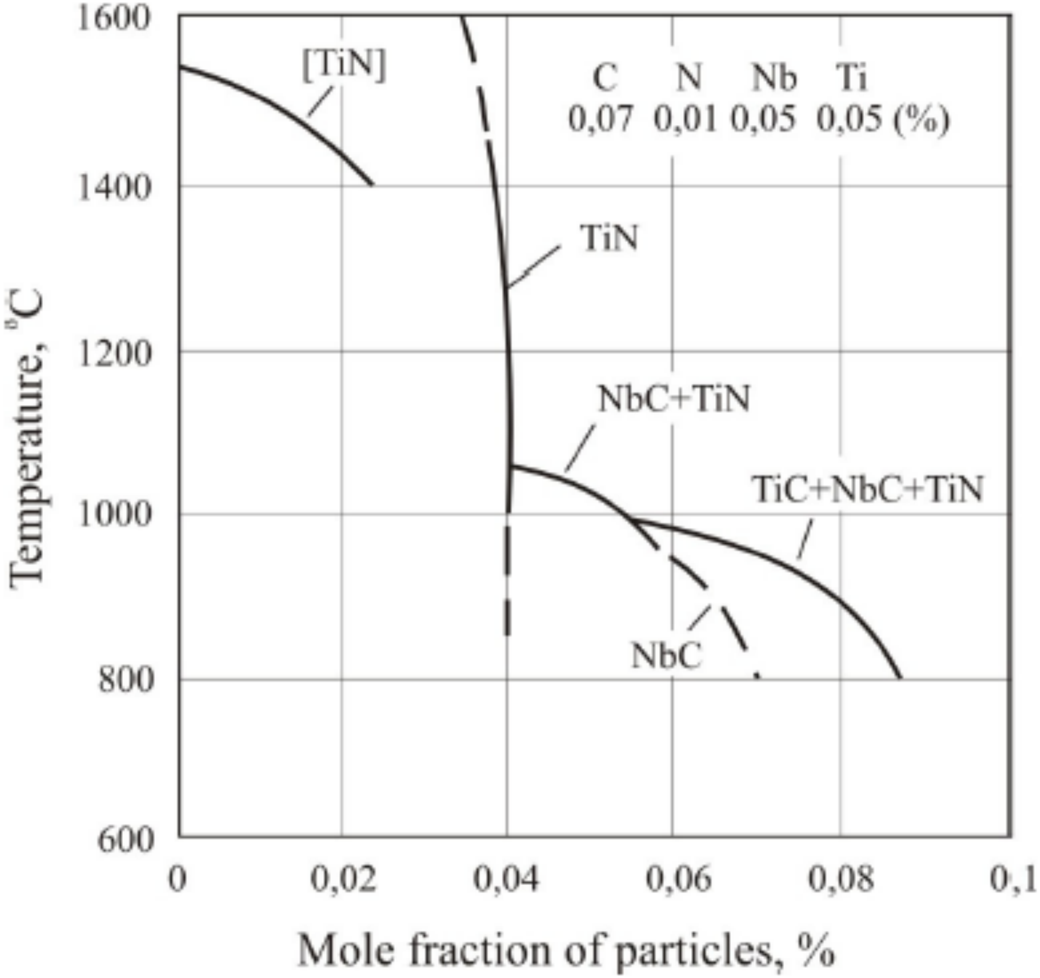
3) Deformation in austenite-ferrite two phase region. Ferrite nucleates and austenite being further work-hardened.



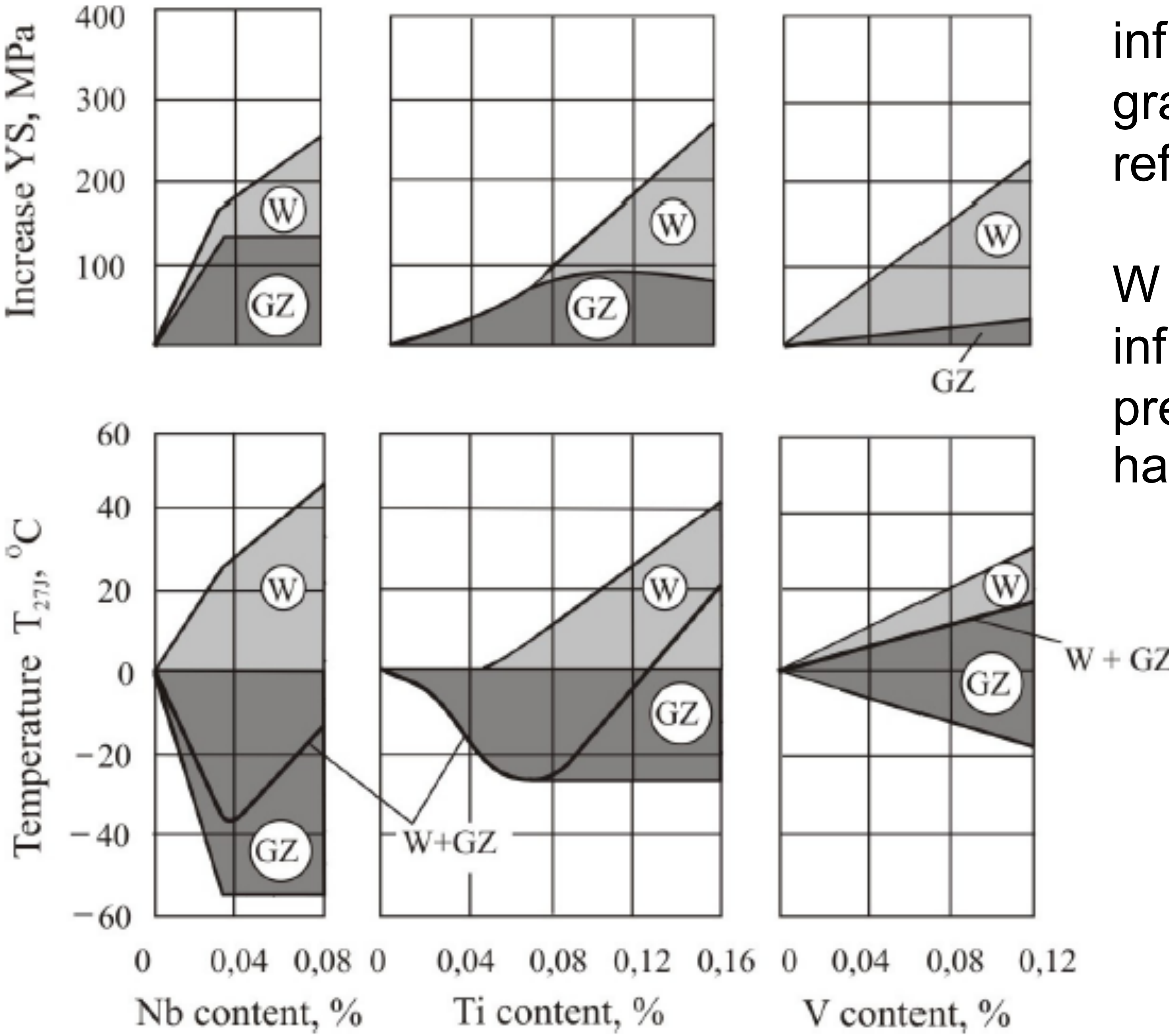


The precipitation and dissolution characteristics of V and Nb compounds in austenite differ significantly. Upon cooling from the forging temperature, NbC begins to precipitate at about 1205 °C. Without subsequent hot work, the precipitates continue to form and coarsen as the temperature falls to 925 °C Continued hot working into the 900 °C temperature range, however, retards austenite recrystallization and precipitation, resulting in the development of a refined austenite grain size.

Vanadium carbonitride precipitation begins at about 950 °C and becomes complete during transformation. Because vanadium carbonitride is a relatively low-temperature product, precipitate coarsening during accelerated cooling from the forge is minimal, and the maximum precipitation-strengthening effect is achieved.



Temperature sequence of nitrides and carbides precipitation in steels with microadditions of Ti and Nb



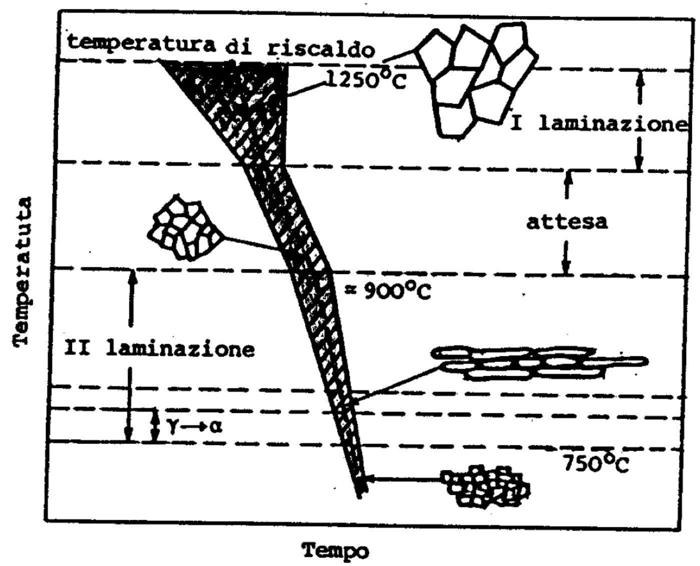
GZ - influence of grain refining,

W - influence of precipitation hardening

Oltre ad affinare il grano, la formazione dei precipitati comporta l'ancoraggio delle dislocazioni.

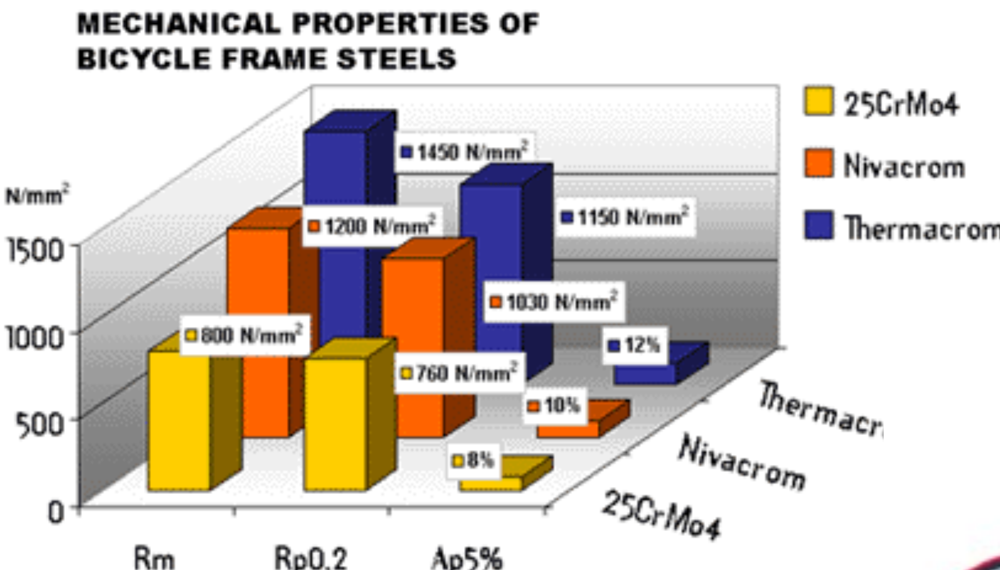
L'ancoraggio prodotto dai precipitati provoca un innalzamento del carico di snervamento, cioè il carico oltre il quale comincia il flusso plastico del materiale.

- Inizialmente si solubilizzano in campo austenitico tutti i composti degli elementi microlegati.
- Si esegue una prima laminazione durante la quale si ha la ricristallizzazione dell'austenite tra una passata e l'altra. A questo punto lo spessore della lamiera è 5 volte quello finale.
- Si lascia raffreddare a 900 °C.
- Seconda laminazione tra 900 e 750°C con riduzione dello spessore, in più passate, di circa 80%.
- Per gli acciai microlegati, questa seconda laminazione allunga il grano austenitico perché i precipitati impediscono la ricristallizzazione quindi si ha una alta velocità di nucleazione della ferrite a seguito del buon rapporto superficie/volume del grano e dell'elevato numero di centri di possibile nucleazione.



Schematizzazione del trattamento di laminazione controllata di un acciaio microlegato ferritico-perlitico; la larghezza dell'area tratteggiata rappresenta lo spessore del laminato.

Un acciaio dalle caratteristiche eccezionali viene prodotto per le tubazioni speciali per le biciclette e utilizzato nei reparti corse. Si tratta di un particolare materiale microlegato siglato 18MCDV6HT che ha innalzato il carico di rottura "all'incredibile" soglia di 1400 MPa, attraverso particolari trattamenti termici.



C 0.16/0.19	Si 0.25/0.40	Mn1.40/1.60
Cr 0.45/0.55	Mo 0.25/0.35	Al 0.02/0.04
V 0.10/0.15	Nickel 0.25	

SuperProdigy

Higher-performance microalloys are now being forged into automotive, agricultural, truck, and heavy-equipment components, many of which have already been documented for their overall cost savings. These include truck crankshafts and connecting rods, motorcycle flywheels, truck-wheel spindles, steering knuckles, lifting hooks and related hardware, and the piston portion of railroad coupling cylinders. Among other microalloy forgings being developed is an auto transmission gear, which is ion-nitrided for increased wear resistance.

One of the most recent successes is a forged microalloy crankshaft for a supercharged auto engine. Going into production just this year, the crank is forged of a vanadium microalloy steel for Ford's 3.8L limited-production engine.

The automaker selected forged MA steel for its high-performance properties, among them minimum tensile and yield strengths of 120,000 and 72,000 psi, respectively, vs. 85,000 and 55,000 psi for the nodular iron commonly used in less demanding engine applications.

While toughness improvements have made forged MAs more appealing to OEMs and designers, and even with these new commercial applications, an industry specification is definitely needed to make designers more comfortable with MA forgings.